

Mirror suppression circuit and receiver using such circuit

The invention relates to a mirror suppression circuit comprising a first quadrature signal path coupled between quadrature signal input and output terminals and including an error correction circuit for correction of amplitude and phase errors in a carrier modulated quadrature signal comprising a pair of in-phase and phase quadrature signal components as well as to a receiver providing quadrature signal processing, comprising an RF input stage subsequently followed by a mixer stage and an IF stage for a selective amplification and level stabilisation of said IF signal and using such mirror suppression circuit.

A receiver of this type is on itself known from e.g. published patent application WO 01/58029. In this known receiver, the RF input stage provides broadband selection and automatic gain controlled amplification of a received RF frequency range, a wanted RF input signal within said received RF frequency range being converted in said mixer stage into a predetermined fixed IF, using a tuning oscillator generating a tuning oscillator signal at a frequency f_{osc} differing from the carrier frequency of the wanted RF input signal by said fixed IF. Quadrature phase splitting may be obtained by the use of resonance amplifier type polyphase filters such as known from e.g. US patent 5,220,686 being hereby incorporated by reference, in the RF or IF signal path or alternatively by the use of quadrature mixers in the mixer stage.

As known, the frequency distribution of the RF transmission signals throughout the received RF frequency range gives rise to frequency dispositions, in which a wanted RF signal finds an unwanted RF signal located at or close to a mirror frequency, i.e. an RF carrier frequency which in the receiver folds back in or close to the baseband modulation frequency range of the wanted RF signal. Such frequency disposition is depicted in the diagram of Figure 1A, in which a wanted RF signal W carrying a baseband modulation signal s is located around a carrier frequency f_w , and the unwanted signal – hereinafter being referred to as mirror signal M – at a carrier frequency $f_M = f_w + 2 \cdot f_{IF} + \Delta f$, in which f_{IF} is the IF receiver frequency equalizing $f_{TO} - f_w$, with f_{TO} being the frequency of the tuning oscillator, and Δf as depicted being smaller than the frequency range of the baseband modulation signal s .

In Figure 1B the frequency disposition of the wanted and mirror signals W and M is depicted in the IF range after RF/IF conversion in the tuning stage. The RF/IF conversion

not only provides down conversion of the wanted RF signal W to a positive frequency f_F , but also folds the carrier frequency of the unwanted mirror signal M around the tuning oscillator frequency f_{TO} to a negative frequency $f_F + \Delta f$, hereinafter also being referred to as unwanted IF mirror signal M , occurring within the frequency range of the useful baseband signal s of the wanted IF signal W .

In a perfect quadrature signal processing receiver the wanted IF signal W can be selectively amplified, while suppressing the unwanted IF mirror signal M without any conversion thereof into the positive frequency domain. In practise, however, imperfections in the quadrature signal processing cannot be prevented due to tolerance spread, parasitic phenomena and/or element mismatch, causing the unwanted IF mirror signal M to fold back into the positive frequency domain. Once this happened, the mirror signal M will intermingle inseparably with the wanted quadrature signal W and will be further processed accordingly. As a result thereof, mirror signals may dominate the AGC control of the IF stage, therewith preventing the wanted IF signal W from obtaining the appropriate IF set level for further signal processing. This in particular holds for wanted IF quadrature signals W being accompanied with relatively strong unwanted IF mirror signals.

The known FM receiver comprises a mirror suppression circuit restoring the mutual amplitude and phase orthogonal balance of the quadrature signal components of the IF signal at the output of the IF stage. This known error correction, however, is restricted to signals with constant amplitude, such as FM signals or other angle modulated signals, and is even within this restriction, not effective to the abovementioned intermingling of the wanted quadrature signal with incoming mirror or image signals caused by the I/Q signal processing of the quadrature signal components occurring in the preceding circuitry, in particular in the polyphase IF filter. Furthermore, strong mirror signals cannot be prevented from dominating receiver control functions, such as the Automatic Gain Control (AGC), or may even overload active receiver circuits causing non-linearities to occur. This in particular makes it difficult to use the abovementioned resonance amplifier type polyphase filters for the selection of the IF signal.

Apart therefrom, in more general sense, the above inevitable imperfections in the processing of quadrature signals result in amplitude and phase errors, which on themselves give rise to intrinsic mirror or image interferences occurring at or close to the negative

carrier frequency of said wanted quadrature signal, without any external supply of mirror signals such as in receiver applications.

Now, therefore, it is a first object of the invention to provide a low cost and more effective mirror suppression or image rejection circuit, which can be generally applied to correct amplitude and phase errors in a quadrature signal.

It is a second object of the invention to provide a mirror suppression circuit, which can be applied in any type of receiver and is not restricted to the use thereof in FM receivers and which prevents strong mirror signals from driving active circuits beyond their linear input range.

This object is achieved in a mirror suppression circuit as described in the opening paragraph according to the invention, which is characterized by a quadrature output of said error correction circuit being coupled through a first filter circuit for a selection of said quadrature signal to a first quadrature input of an error detection circuit, said first quadrature signal path being coupled prior to said first filter circuit through a second quadrature signal path to a second quadrature input of said error detection circuit, said error detection circuit detecting amplitude and phase errors and providing amplitude and phase control signals to amplitude and phase control inputs of said error correction circuit for a negative feed back of said amplitude and phase errors to said error correction circuit, said amplitude control signal varying with at least one of products $I_w \cdot I_{ref}$ and $Q_w \cdot Q_{ref}$ and said phase control signal varying with at least one of products $I_w \cdot Q_{ref}$ and $Q_w \cdot I_{ref}$, I_w and Q_w , respectively I_{ref} and Q_{ref} , representing the in-phase and phase quadrature signal components of said quadrature signal at the first quadrature input of the error detection circuit, respectively the in-phase and phase quadrature signal components of a quadrature reference signal occurring at the negative carrier frequency of said quadrature signal at the second quadrature input of the error detection circuit.

By applying this measure according to the invention, the error detection circuit receives at its first quadrature input the selected wanted quadrature signal from the first filter circuit and at its second quadrature input the unwanted quadrature mirror signal from the second quadrature signal path. In contrast to the error detection circuit of the known FM receiver receiving amplitude limited oscillator signals at its first and second quadrature input, both selected wanted quadrature signal and unwanted quadrature mirror signal are not amplitude limited. The error detection circuit derives therefrom amplitude and phase

control signals, which apart from the amplitude and phase imbalance between the in-phase and phase quadrature signal components of the wanted signal also vary with amplitude variations of said both selected wanted quadrature signal and unwanted quadrature mirror. The mirror suppression circuit is therewith transparent for both angle as well as amplitude modulated signals, allowing use thereof in all type of receivers, including FM and AM receivers.

According to the invention these amplitude and phase control signals are coupled to the error correction circuit for a negative feedback of the amplitude and phase errors as well as the amplitude variations of both selected wanted quadrature signal and unwanted quadrature mirror signal. As a result thereof, the quadrature signal at the output of said error correction circuit is pre-corrected for amplitude and phase errors introduced subsequently in the first filter circuit, whereas both wanted quadrature signal and unwanted quadrature mirror signal are being stabilised against variations. Compared with said prior art, the measure according to the invention not only result in a considerably improved image frequency suppression, but also prevents the first filter circuit from being overloaded.

According to an aspect of the invention, a receiver providing quadrature signal processing and comprising an RF input stage subsequently followed by a mixer stage for a conversion of an RF signal into an IF signal and an IF stage for a selective amplification of said IF signal, is characterized by a mirror suppression circuit having its quadrature signal input coupled to a quadrature output of the mixer stage and said first filter circuit being part of said IF stage and having a resonance frequency at the carrier frequency of said IF signal

By applying this measure according to the invention, the IF stage of the receiver is used not only for selective IF signal amplification, but is also part of the mirror suppression circuit and is prevented from being overloaded at the reception of strong mirror signals.

To optimize the detection of amplitude and phase errors, said amplitude control signal preferably varies with $I_w \cdot I_{ref} + Q_w \cdot Q_{ref}$ and said phase control signal with $I_w \cdot Q_{ref} - Q_w \cdot I_{ref}$.

To obtain said quadrature reference signal, the second quadrature signal path preferably includes inverter means.

In another preferred embodiment of the invention, said second quadrature signal path includes a second filter circuit for a selection of said quadrature reference signal and/or

may be coupled to the first quadrature signal path subsequent to the error correction circuit.

A further preferred embodiment of the invention is characterized by said second quadrature signal path comprising said signal inverter coupled between the first quadrature signal path and said second filter circuit, said second filter circuit being identical to said first filter circuit.

The invention will now be explained in more detail with reference to the accompanying drawing, in which:

Figures 1A and 1B are amplitude (A)-frequency (ω) diagrams representing a wanted carrier modulated quadrature signal and its mirror signal;

Figure 2 an embodiment of a mirror suppression circuit according to the invention;

Figure 3 an embodiment of a receiver comprising a mirror suppression circuit according to the invention.

Figure 2 shows an embodiment of a mirror suppression circuit according to the invention comprising a first quadrature signal path S1 coupled between quadrature signal input and output terminals I_i, I_q and O_i, O_q including an error correction circuit ECC for correction of amplitude and phase errors in a carrier modulated quadrature signal comprising a pair of in-phase and phase quadrature signal components. A quadrature output O_{ci}, O_{cq} of said error correction circuit ECC is coupled through a first filter circuit PF1 having a resonance frequency at the carrier frequency of said quadrature signal to a first quadrature input Id_{i1}, Id_{q1} of an error detection circuit EDC, said first quadrature signal path S1 being coupled prior to said filter circuit PF through a second quadrature signal path S2 to a second quadrature input Id_{i2}, Id_{q2} of said error detection circuit EDC through an inverter INV for an inversion of the in-phase and phase quadrature signal components of the above carrier modulated quadrature signal. This error detection circuit EDC detects amplitude and phase errors δA and $\delta \Phi$, respectively, and provides amplitude and phase control signals A_c and P_c to amplitude and phase control inputs A and P of said error correction circuit ECC for a negative feed back of said amplitude and phase errors δA and $\delta \Phi$ to said error correction circuit ECC, said amplitude control signal A_c varying with at least one of products $I_w \cdot I_{ref}$ and $Q_w \cdot Q_{ref}$ and said phase control signal varying with at least one of products $I_w \cdot Q_{ref}$ and $Q_w \cdot I_{ref}$, in which I_w and Q_w respectively represent the

in-phase and phase quadrature signal components of the quadrature signal at the first quadrature input $Idi1$, $Idq1$ of the error detection circuit EDC, and in which I_{ref} and Q_{ref} , respectively represent the in-phase and phase quadrature signal components of a quadrature reference signal occurring at the negative carrier frequency of said quadrature signal supplied to the second quadrature input $Idi2$, $Idq2$ of the error detection circuit EDC. Although the invention can in principle be applied with the amplitude control signal Ac varying with either product $I_w * I_{ref}$ or $Q_w * Q_{ref}$ and said phase control signal varying with either product $I_w * Q_{ref}$ or $Q_w * I_{ref}$, the amplitude control signal Ac is to vary by preference with $I_w * I_{ref} + Q_w * Q_{ref}$ and said phase control signal Pc with $I_w * Q_{ref} - Q_w * I_{ref}$.

To obtain these amplitude and phase control signal Ac and Pc , the error detection circuit EDC comprises multiplier stages MII , MQQ , MIQ and MQI , having first input terminals being coupled respectively to the output terminals Oi , Oq , Oi and Oq , and second input terminals being coupled respectively to the output terminals Oci , Ocq , Oci and Ocq of the quadrature output of the error correction circuit ECC to provide said products $I_w * I_{ref}$; $Q_w * Q_{ref}$; $I_w * Q_{ref}$ and $Q_w * I_{ref}$, respectively. Outputs of multiplier stages MII and MQQ are being coupled to an adder circuit ADD and outputs of multiplier stages MIQ and MQI are being coupled to an difference circuit DIF , to form respectively the sum of $I_w * I_{ref}$ and $Q_w * Q_{ref}$, and the difference of $I_w * Q_{ref}$ and $Q_w * I_{ref}$. Outputs of the adder circuit ADD and the difference circuit DIF are being coupled through low pass filters LPA and LPP to the amplitude and phase control inputs A and P of the error correction circuit ECC to supply thereto the above amplitude control signal Ac varying with $I_w * I_{ref} + Q_w * Q_{ref}$ and said phase control signal Pc varying with $I_w * Q_{ref} - Q_w * I_{ref}$.

In an alternative embodiment of the invention (not shown), the inverter INV is dispensed with by providing an appropriate signal inversion within the multiplier stages MII , MQQ , MIQ and MQI .

The error correction circuit ECC comprises a phase correction circuit 1-5 including a differential stage 1 following the phase control input P converting said phase error signal $\delta \Phi$ into a differential pair of first and second phase error signals $+0,5 \delta \Phi$ and $-0,5 \delta \Phi$ and supplying the same to modulation signal inputs of first and second multipliers 2 and 3, respectively, said first and second multipliers 2 and 3 having inputs coupled to the in-phase and phase quadrature paths I and Q of the first quadrature signal path $S1$ and having outputs coupled through first and second adder device 4 and 5 to the phase quadrature and

in-phase paths Q and I, respectively, therewith pre-correcting the in-phase and phase quadrature signals of the first quadrature signal path S1 with $-\delta\Phi$ to pre-compensate for the phase error $\delta\Phi$ occurring in the first filter circuit PF1. The error correction circuit ECC also comprises an amplitude correction circuit 6-8 including a differential stage 6 following the amplitude control input A converting said amplitude error signal δA into a differential pair of first and second amplitude error signals $+0.5\delta A$ and $-0.5\delta A$ and supplying the same to third and fourth multipliers 7 and 8, respectively, said third and fourth multipliers 7 and 8 being included in said in-phase and phase quadrature paths I and Q, therewith pre-correcting the in-phase and phase quadrature signals of the first quadrature signal path S1 with $-\delta A$ to pre-compensate for the amplitude error δA occurring in the first filter circuit PF1.

The amplitude and phase control signals A_c and P_c not only vary with the quadrature amplitude and phase imbalance of the quadrature signal of the first quadrature signal path S1, but also with the amplitude variations of this quadrature signal due to the linear signal processing in both first and second quadrature signal paths S1 (i.e. in the first filter circuit PF1) and S2. Dependent on spread, current settings, bias voltage, etcetera, an ideal situation can be obtained, in which the amplitude and phase control signals A_c and P_c will fully compensate all cumulated amplitude and phase errors of all circuitry preceding and inclusive the error correction circuit ECC and pre-compensate all amplitude and phase errors of the first filter circuit PF1, such that the quadrature signal at the quadrature output O_i , O_q is free from any amplitude and phase error. In this event, the compensation is effective for all amplitude values of the wanted quadrature signal W and the mirror signal M as shown in Figures 1A and 1B. This allows to implement said first filter circuit PF1 with active polyphase filters, e.g. active polyphase filters using resonance amplifiers, such as known from the above cited US patent 5,220,686, without mirror signals driving the transconductance amplifiers used therein, beyond their range of linear operation.

In a non-ideal situation, the amplitude and phase control signals A_c and P_c may comprise small residual errors, which can be reduced by an automatic gain control using the variations of the amplitude and phase control signals A_c and P_c caused by the amplitude variations of the wanted quadrature signal W and the mirror signal M to stabilise these amplitude and phase control signals A_c and P_c .

In the embodiment of the mirror suppression circuit of Figure 2, the second quadrature signal path S2 is coupled to the first quadrature signal path S1 subsequent to the error correction circuit ECC. The invention may well be applied by coupling the second quadrature signal path S2 to the first quadrature signal path S1 prior to the error correction circuit ECC (not shown).

Figure 3 shows an embodiment of a receiver comprising a mirror suppression circuit according to the invention and providing quadrature signal processing comprising an RF front end FE coupled to antenna means ANT such as known from the cited published patent application WO 01/58029 and comprising (not shown) an RF input stage coupled to the antenna means ANT and followed by a mixer stage for a conversion of an RF signal into an IF signal using a tuning oscillator having a tuning frequency f_{TO} . With an RF frequency disposition of a wanted RF signal s around a wanted RF carrier f_w and a strong mirror signal at f_M , as depicted in the diagram of Figure 1A, the RF front end FE provides a quadrature IF signal having a frequency disposition as depicted in the diagram of Figure 1B.

This IF quadrature signal is being supplied to first quadrature signal path S1, which includes error correction circuit ECC followed by a quadrature IF filter stage IFW functioning as first filter circuit and having a resonance frequency at the carrier frequency of said quadrature IF signal, i.e. f_{IF} . The selected quadrature IF signal is being supplied to a demodulation circuit DEM to demodulate the same into the baseband modulation signal, e.g. an stereophonic audio signal, which is further processed in an audio signal processor ASP and reproduced with stereo left and right loudspeakers L and R. The demodulation circuit DEM may be an FM, PM or AM demodulator, dependent on the RF signal modulation type.

According to the invention the first quadrature signal path S1 is being coupled on the one hand from the quadrature output of the IF filter stage IFW to a first quadrature input $Idi1$, $Idq1$ of an error detection circuit EDC. On the other hand, the first quadrature signal path S1 is coupled prior to said quadrature IF filter stage IFW through second quadrature signal path S2 to second quadrature input $Idi2$, $Idq2$ of said error detection circuit EDC. In the embodiment shown in this Figure 3, the second quadrature signal path S2 includes a cascade connection of an inverter INV and a filter circuit IFM, which preferably is identical to the IF filter stage IFW, said cascade connection being coupled

between the quadrature output of the error correction circuit ECC and the second quadrature input $Idi2$, $Idq2$ of said error detection circuit EDC. The inverter INV and the filter circuit IFM operate together as second filter circuit having a resonance frequency at the negative IF frequency, therewith selecting mirror signals such as mirror signal M in Figure 1B.

As clarified above with respect to the mirror suppression circuit of Figure 2, both amplitude and phase errors of the quadrature signal at the output of the error detection circuit EDC and IF signal amplitude variations due to variations in RF fieldstrength, are negatively fed back to the error correction circuit ECC and therewith suppressed. This prevents strong mirror reception from deteriorating the receiver performance and allows to use active circuitry, such as resonance amplifier type polyphase filters, in the IF filter stage IFW without introducing non-linearities.

The invention is not limited to the embodiments explicitly disclosed. It may well be possible without leaving the scope and spirit of the invention, to dispense with the differential stages 1 and 6 e.g. by correcting for both phase and amplitude mismatch in either the in-phase path I only, or in the phase quadrature path Q only, or to carry out such corrective measure on in-phase and phase quadrature IF oscillator signals VCOI and VCOQ of the local IF tuning oscillator included in the RF front end FE and preceding the first quadrature signal path S1.

Furthermore, the second filter circuit in the receiver of Figure 3 may well be omitted or may be implemented with a selectivity deviating from the IF filter stage IFW.

The invention is embodied in each new characteristic and each combination of characteristics. Any reference signs do not limit the scope of the claims. The word "comprising" does not exclude the presence of other elements than those listed in a claim. Use of the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.